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# Woods Hole Oceanographic Institution

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## CONTINUATION OF UNDERSEA ACOUSTICS RESEARCH

by

Gordon K. Glass

July 1977

TECHNICAL REPORT

Prepared for the Office of Naval Research under Contract N00014-70-C-0305; NR 083-325.





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# CONTINUATION OF UNDERSEA ACOUSTICS RESEARCH

by

Gordon K. Glass

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Woods Hole, Massachusetts 02543



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TECHNICAL REPORT

*Prepared for the Office of Naval Research under Contract N00014-70-C-0205; NR 083-325.*



**Approved for Distribution** Earl E. Hays

**Earl E. Hays, Chairman**
**Department of Ocean Engineering**

## ABSTRACT

This is the final report of Contract N00014-70-C-0205; NR 083-325, between the Woods Hole Oceanographic Institution and the Office of Naval Research. This contract supported, from 1 August 1969 - 31 December 1976, a program of basic research whose broad aim was to investigate those aspects of undersea acoustic propagation that relate directly to present and future Naval requirements.

A review of the highlights of the research in each area, and a bibliography of published and unpublished reports, is presented.

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# INTRODUCTION

This is a final report of the research activities under the Office of Naval Research Contract N00014-70-C-0205;NR 083-325, at the Woods Hole Oceanographic Institution during the period from August 1969 to December 1976.

The work was performed by members of the Department of Geology and Geophysics until 1971 and then after internal reorganization at this Institution by these people, now under the auspices of the Department of Ocean Engineering. The seven year period of work reported herein was preceded by Contract Nonr-4029(00); NR 260-101, and has been superseded by Contract N00014-77-C-0196. In order to preserve continuity and efficiency, each contract change has included transfer of equipment, reports and contractual obligations.

# SUMMARY OF INVESTIGATIONS

## Ocean Acoustics

The principal goal of the research performed under this contract was to investigate those aspects of undersea acoustic propagation that relate directly to present and future Naval requirements. Our response to currently perceived Navy needs has been the single major factor in shaping the general direction of our research. We have completed various studies in such diverse areas as undersea ambient noise, ray and mode theory propagation analysis, acoustic dispersion, volume reverberation, split sound channel effects, amplitude and phase fluctuations at low frequencies, acoustic-internal wave effects, temporal and spatial coherence, bottom reflectivity, long-range side-looking echo ranging, etc. As a necessary adjunct to these programs a number of unique and generally useful instruments have been developed. They include core head and trawl wire velocimeters, high frequency sonars for volume reverberation, ambient noise

processors, environment sensing depth controlled towed fish (salinity, temperature, pressure, sound velocity), pulse and Doppler precision acoustic navigation systems, analog ambient noise buoys, and a digital acoustic buoy. A computer system devoted solely to acoustic signal processing has been developed. We have also responded to Navy requirements through participation in several large-scale acoustic exercises including projects NEAT I and II and other LRAPP sponsored activities. The primary results of these endeavors have appeared in the form of Woods Hole Technical Reports, the publication of scientific papers in both the classified and unclassified literature, the presentation of oral reports at various technical society symposia and Navy sponsored workshops, and technical lectures and briefings to an assortment of Navy and NATO organizations. This material is included in the bibliography appended to this report.

An important, though less reported, function throughout the contract period has been our capacity to function as an advisory agency to a wide variety of Navy activities. These have included representation on Navy panels concerned with oceanographic and acoustic problems in the Mediterranean, towed array systems, mine defense, ambient noise, and low frequency propagation. Advisory discussions with the Sixth Fleet, NAVOCEANO, FNWC, NOL, USC, SACLANT, COMSUBDEVGRU TWO, Naval War College, Navy League, SUBFLOT TWO and others have occurred on a continuing basis.

The following paragraphs summarize the major areas of research pursued under the auspices of this contract.

<u>Acoustic Navigation</u>

A new and novel type of acoustic navigation has been developed under the initial sponsorship of this contract. It operates on the Doppler

principle, using three acoustic beacons moored close to the ocean bottom. Each beacon emits a high frequency stable acoustic tone near 13 kHz. The tones are received by the object to be tracked and are examined for Doppler shift. Accuracy over a short time interval is several centimeters. Together with ARPA support, the system has been combined with a conventional pulse type (travel tone) acoustic navigation system that has enabled the formation of spatial synthetic apertures in the ocean for the purpose of acquiring spatial coherence data. The combined pulse Doppler system has also made possible the unique acoustic fluctuation and coherence work performed under this and other contracts.

Long Range Echo Ranging

Two long-range side-looking echo ranging schemes were developed and tested at sea near the Blake-Bahama escarpment. The first system employed a deep-towed (2000') hydrophone array and explosive acoustic sources and mapped submarine features at a range of about 200 NM. The second system used a similar array together with a coherent, swept frequency acoustic source. Processing gain using matched filter techniques was about 15 db indicating that a 300 NM ocean path is sufficiently phase stable to support coherent processing schemes.

Microearthquakes

An acoustic navigation system was used to track the position of drifting sonobuoys for the purpose of forming arrays to detect and locate small seismic events near the Mid-Atlantic Ridge. The frequency, magnitude and spectral characteristics of these microearthquakes were analyzed. The location of many events was pinpointed, using maxim likelihood spectral techniques, to within 200 meters.

Modified Acoustic Ray Theory

A ray theory of acoustic propagation designed to yield accurate range estimates at low frequencies has been developed. Certain diffraction effects are accounted for in a ray theoretic framework and the calculations can be taken through shadow zones and caustics. The modified ray theory has been compared, via computer modeling, with exact normal mode solutions.

Ambient Noise

Quantitative ambient noise measurements in the Atlantic, Caribbean, and Mediterranean have been reported. Ambient noise analysis from project NEAT and other LRAPP activities have also been reported.

Volume Reverberation

Volume reverberation data in the Atlantic and Mediterranean have been analyzed and reported. Single frequency and broadband analyses have been performed. Reverberation from the deep scattering layer has been compared extensively with simultaneous biologic sampling. Correlations between scattering strength, oceanographic features, and biologic species have been made.

SOFAR Channel Transmission

Dispersed high-order modes were observed at frequencies up to 300 Hz and ranges of 600 km for shots detonated in a Mediterranean SOFAR channel. WKB mode theory was used to predict accurately the observed group-velocity profiles, and to predict the pressure field in channels with arbitrary velocity profile. Observations of combined ray and mode behavior are also predicted. A computer code was developed to estimate the wideband propagation loss that requires an order of magnitude fewer calculations than an harmonic analysis.

Fluctuations and Coherence

A program to investigate acoustic fluctuations and coherence effects in low frequency, long-range transmissions has constituted a major portion

of the research conducted under the auspices of this contract during the years 1972-1976. The program has been a combined experimental and theoretical effort and has resulted in a number of new measurement techniques and theoretical developments. These innovations are described in complete detail in the appended list of publications.

One of the more significant technical advances has been the development of synthetic aperture techniques for measuring acoustic fluctuations and coherence. The technique is based on an acoustic Doppler navigation system capable of resolving relative motion of a hydrophone (or other tracked object) to within a fraction of a meter. This system has enabled the formation of synthetic apertures up to 10 km in length. The Doppler system has been combined with a conventional pulse type navigation system (based on the measurement of acoustic travel times rather than Doppler shift) to form a powerful acoustic navigation tool that gives absolute positions to within five to 10 m and relative positions to within 0.1-1 meter. Also of note has been the development of low frequency (100 and 200 Hz) self-contained, moored acoustic sources. These have found extensive use in our fluctuation studies and are now finding their way into other Navy programs.

At-sea measurement of acoustic fluctuations were made in a series of four major experiments. Fluctuations of signal amplitude, phase and phase-rate were observed on a function of depth, range and frequency. Signals were received on ship-suspended drifting hydrophones, hydrophones suspended from drifting sonobuoys and moored hydrophones at various depths. The moored hydrophones are coupled to small data processing and digital recording buoys developed specially for this work. Data have been used extensively to compare observed fluctuations with predictions based on

theoretical ideas developed at Woods Hole and elsewhere.

Some of the more significant findings of this research have been:

1) For time periods greater than the local inertial period and less than the local buoyancy period acoustic fluctuations, and therefore temporal and spatial coherence, are strongly dependent on ocean internal waves unless the number of acoustic paths is large.

2) When the number of acoustic paths is large, by virtue of source and receiver placement (for example, at very long ranges) fluctuations are dominated by multipath propagation and the received signal obeys the statistics of a phase random process.

3) Signal fluctuations scale with frequency, at least in the hundred to several hundred Hz range, as predicted by weak scattering theories.

The Development of Computer Use

Between 1969 and 1973 the Acoustics Group used the computers provided by the shipboard computer systems. These systems were based around Hewlett Packard minicomputers located on each ship, plus one system on shore. These systems consisted of a H/P 2116 computer, a paper tape reader/punch, a magnetic tape drive, and a Calcomp plotter. The shore system was used to develop programs to be run at sea.

Each project had its own specialized computer peripherals. The Acoustics Group owned a magnetic tape drive, an analog to digital converter, a graphics terminal, and a time code generator. These devices, were used under computer control to acquire data from the ocean and record it on magnetic tape for later analysis on shore.

The length and complexity of the acquisition programs, and hence the sophistication of the experiment, was limited by the available computer

hardware. A small change to a program required around 30 minutes, so programs seldom exceeded 600 lines of code. As acoustics experiments became more complex, including such features as Fourier transforms and phase analysis, the programs required to control these experiments grew beyond the capability of the available hardware. In 1973 the Acoustics Group purchased a H/P 2100 minicomputer system to aid in the development of their acquisition and analysis programs.

The 1973 data analysis facility consisted of the earlier peripherals plus a H/P 2100 computer, two disc drives, one magnetic tape drive, and a paper tape reader/punch. The disc drives, running with the Disc Operating System software (DOS-M), gave the acousticians the capability of writing acquisition programs which included on-line signal processing options. The data analysis facility was expanded in 1974 with a Calcomp plotter, in 1975 with a high speed line printer and a console terminal, and in 1976 with a medium speed line printer for use at sea.

This facility has successfully provided software support for on-line acoustic data acquisition. During the time period funded by this contract, computer applications have grown from very simple data logging programs to very sophisticated control/acquisition/navigation programs.

Ocean Dynamics and Acoustic Environment

Throughout the life of the contract there was a continuous and vigorous program of studying the spatial variations in the ocean with an appreciation of the effect that these variations have on acoustic transmission in the ocean. Observations have been made simultaneously with transmission experiments, but the basic effort was to study the statistical properties of ocean variability.

The backbone of these studies has been several generations of tow

fish systems which evolved from a weight-depressed, wire-controlled depth, single sensor package to a neutral tow body, electronically controlled depth, multi-sensor package. A schematic of the system (almost totally developed under this contract beginning in 1972) as last flown is shown in Figure 1. The proven capabilities of this system are as follows:

1) Has been towed for a total of 1000 hours at speeds of 408 knots.

2) Has tracked an isopleth to within ±1 meter for 36 hours.

3) Has flown at depths of 10 to 800 meters.

4) Has towed vertically separated sensor packages from eight to 70 meters apart with 5% variation in separation.

5) Has flown for over three days on a single deployment without degradation of performance or signal.

6. Has measured temperature, vertical temperature gradients, salinity, sound velocity, dissolved oxygen and ocean currents.

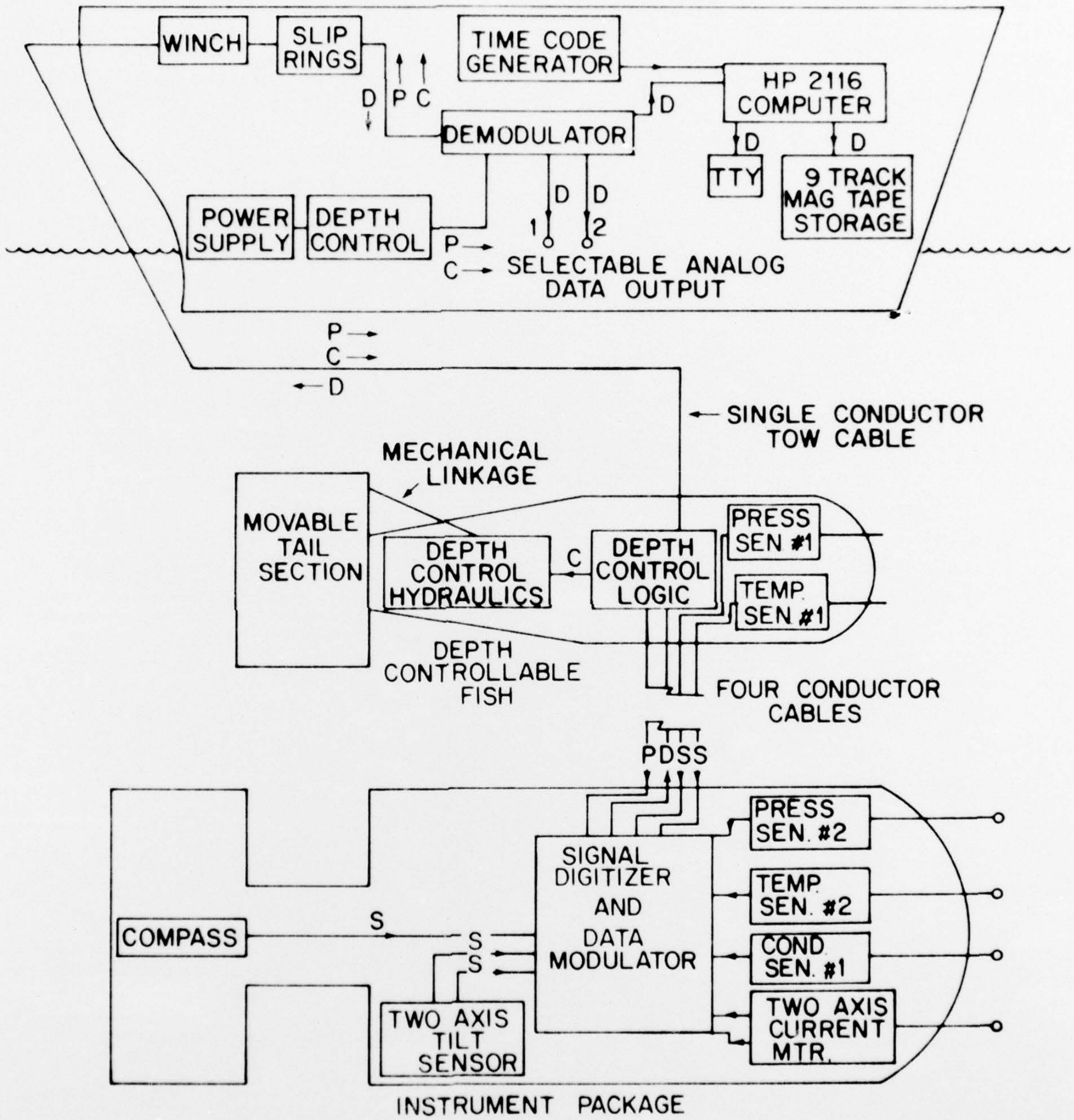
It is presently fully operational, though still being improved. A complete and annotated list of tows are shown in the table, without reference to the tow system deployed.

The objective of our tow fish program has been to enhance our understanding of the ocean by describing the spatial variability of its density and current fields and delineating the dynamic processes which are actively responsible for the variability. This variability is known to degrade coherent acoustic propagation in the ocean and is therefore a limiting factor to coherent array design.

The results of the program have had a direct input to acoustic prediction via the modeling of internal waves. Our measurements of the energy spectrum in the vertical displacement field, as a function of

horizontal wavenumber has demonstrated the isotropy and stationarity of internal wave induced motions and has made an important contribution to demonstrating the universality of this field. As the first set of measurements well below the surface layers, it had a special value at the time. The continuation of this study, into the vertical coherence of the displacement field, is expected to play a role in the present activity of revising (and tuning) of these models. The most recent efforts have been towards investigating fine structure in the ocean (i.e., scales smaller than coherent internal waves) and its generation by shear currents in the ocean.

A second area of continued interest has been frontal structures (both surface and subsurface) in the ocean. Their role in distributing acoustic propagation is qualitatively obvious, because of the generally sharp change of temperature (hence sound velocity) across them (gradients 1000 times large than normal). Our interest has been directed at the stability of fronts, work which will hopefully lead to an understanding of frontolysis.




<u>CODES</u>

S = SENSOR SIGNAL
D = DIGITIZED DATA
P = POWER
C = DEPTH CONTROL

SUMMARY OF TOW DATA[1]

| Tow Nos. | Location | Month & Year | Depth of tows (m) | Length of tracks (km) | Main Sensor Suite[2] | Vertically Separated Sensors | Primary Purpose of Program |
|---|---|---|---|---|---|---|---|
| 101,102 | W. Mediterranean | 7/70 | 400,450 | 220 | P,T,C | - | Discontinuity in Levantine Intermediate Water (L.I.W.) |
| 201-203 | W. Mediterranean | 7/70 | 375,275, 135 | 330 | P,T,C | - | Interaction between L.I.W. and surface waters |
| 301,401 | S. Sargasso | 3/71 | 560-680 | 750 | P,T,C,SV | - | Large-scale displacement of isopycnal surface |
| 501-503 | S. Sargasso | 2/72 | 620-660 | 200 | P,T,C,SV | SV | Short-time stationarity of isopycnal surface |
| 504-509 | N. Sargasso | 3/72 | 25,45 | 600 | P,T,C,SV | SV | Structure of the mixed layer |
| 601-606 | S. Sargasso | 9/72 | 600-640 | 210 | P,T,C,SV | - | Short-time stationarity of isopycnal surface |
| 607 | S. Sargasso | 10/72 | 300 | 170 | P,T,C,SV | - | Support of propagation study |
| 701-704 | S. Sargasso | 4-6/73 | 700-800 | 2700 | P,T,C | P,T | Identification of quasigeostrophic scales (MODE) |
| 801-803 | Equatorial Atlantic | 6-7/74 | 10-160 | 1200 | P,T,C,DO,CV | - | Profiling of equatorial undercurrent (GATE) |
| 900 | SW Sargasso | 9/74 | 500 | 350 | P,T,C,SV | - | Support of propagation study |
| 901-964 | S & N Sargasso | 10/75 | 280-400 640-780 | 2500 | P,T,C | P,T | Vertical coherence of spatial density variations |
| 951,952 | Bermuda | | | | | | Fine-scale temperature inversions (FAME) |
| 1001-1005 | S Sargasso | 3/76 | 20-200 | 1400 | P,T,C,CV | T | Current field in oceanic fronts |
| 1100 | California Current | 1/78 | | in preparation | | | Coherence of fine-scale current and density variations |

[1] Support for tows 100-600,900 was from ONR, Contract N00014-70-C-0205.
Support for 700 series was from NSF/IDOE, Grant GX 34906.
Support for 800 series was from NSF (GARP), Grant GA 40343.
Support for 901-964 was from NSF, Grant DES 19608.
Support for 1000 series was from ONR, supplement to Contract N00014-74-C-0262.
Preparation for 1100 series is from ONR, N00014-77-C-0196.

[2] p = pressure, T = temperature, C = conductivity, SV = sound velocity, DO = dissolved oxygen
CV = current vector.

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